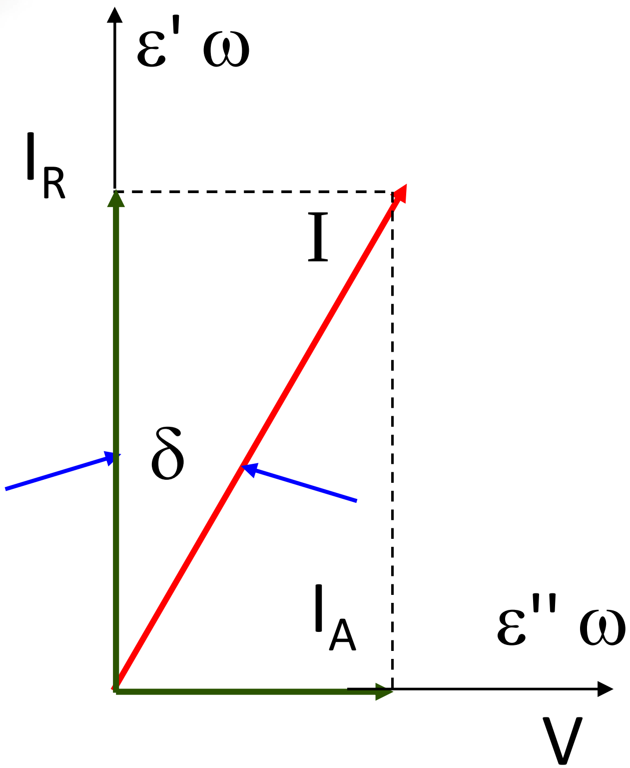
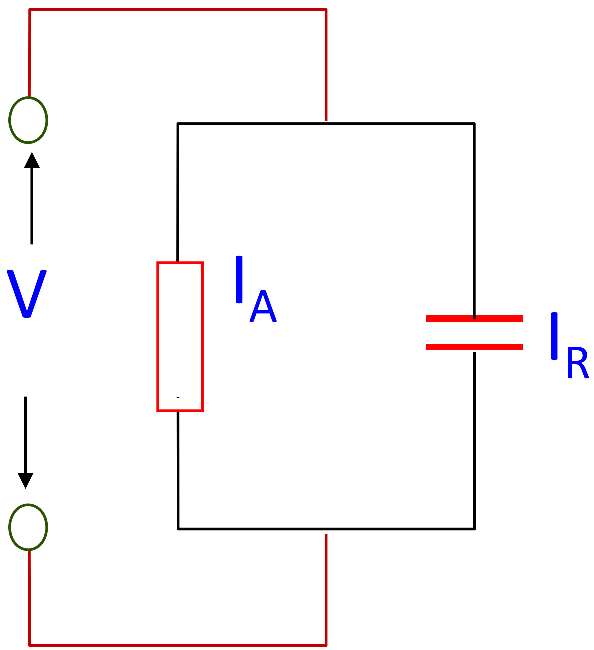
Dielectric Losses

It is common to use a measure quality factor called "tangens delta" (tg δ):

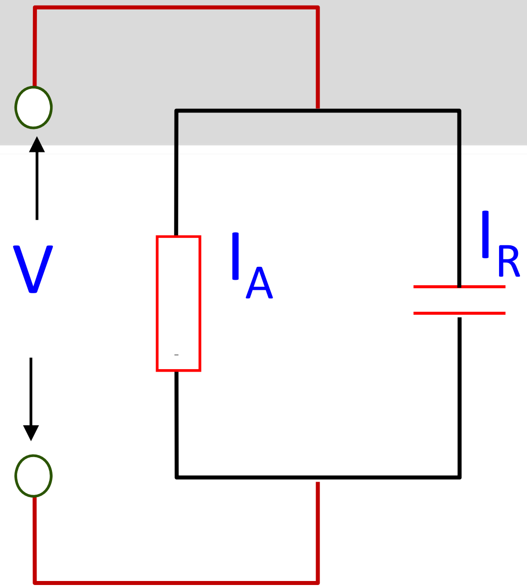
$$tg\,(\delta) = \frac{I_A}{I_R} = \frac{\varepsilon''}{\varepsilon'}$$





Dielectric Losses

The current component I_A is in phase with the applied voltage V and it corresponds to the imaginary part ε'' of the dielectric function multiplied by ω.



The out-of-phase current component I_R is given by the real part ε' of the dielectric function multiplied by ω

R would be infinite for an ideal dielectric

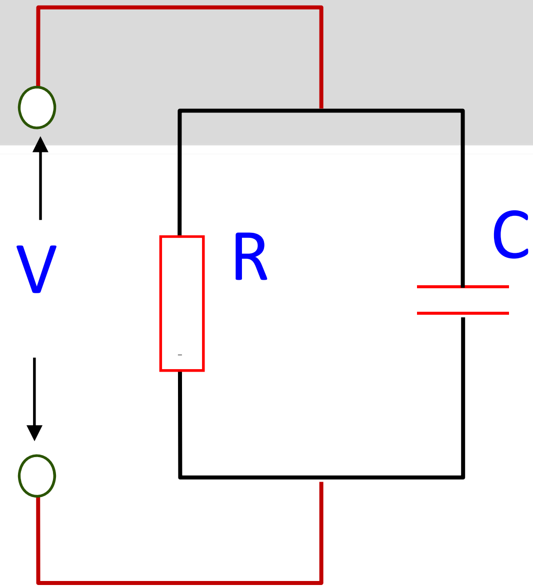
It is obvious that the smaller the angle δ or $\mathrm{tg}\ \delta$, the better with respect to power losses

Dielectric Losses

The values of the ohmic resistor and the capacitor are frequency dependent

$$C = \frac{A \cdot \varepsilon'}{d}$$

$$R = \frac{d}{\omega \cdot A \cdot \varepsilon''}$$



The total power loss is calculated in terms of tg (δ) by substituting for ε'' by ε' · tg (δ)

$$L_A = \omega \cdot |\varepsilon''| \cdot E^2$$

$$tg\,(\delta) = \varepsilon'' / \varepsilon'$$

$$L_A = \omega \cdot \varepsilon' \cdot E^2 \cdot tg\,(\delta)$$

Special Dielectrics

It is not obligatory for some special materials to apply an external electrical field to get a polarization

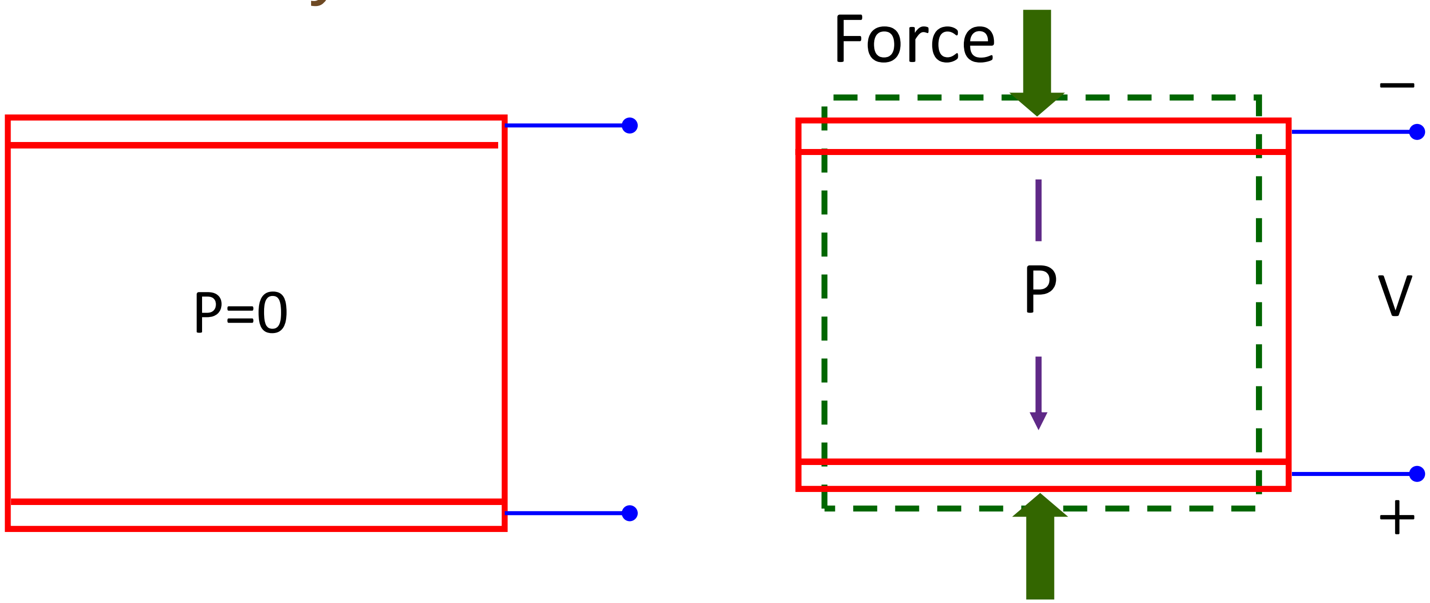
The polarization may come about by other means like the case of ***Piezoelectricity*** and ***Ferro electricity***

Piezoelectricity

When crystals with nonuniform charge distribution are mechanically deformed, the positive and negative charge centres are shifted by different values

The overall crystal remains electrically neutral

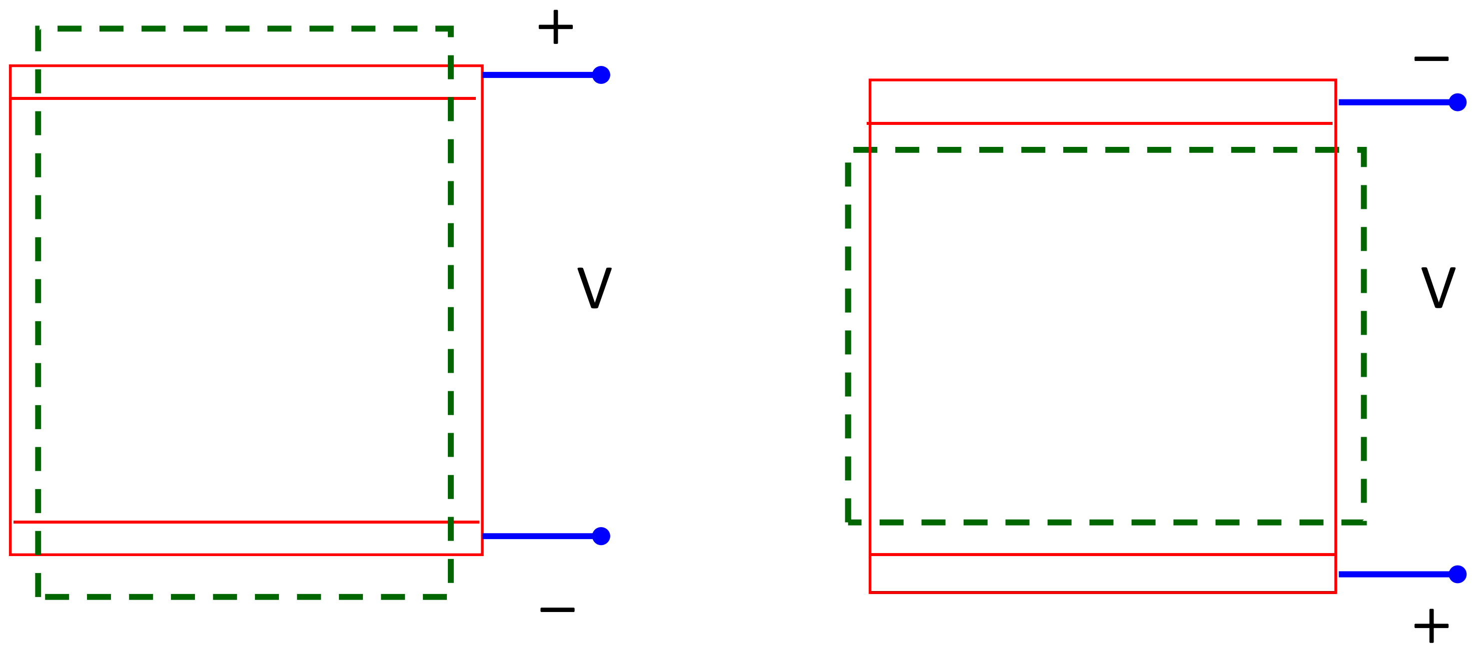
The shifting in the charge centres results in an electric polarization within the crystal known as Piezoelectricity



Piezoelectricity

The production of mechanical deformation by polarization is also possible

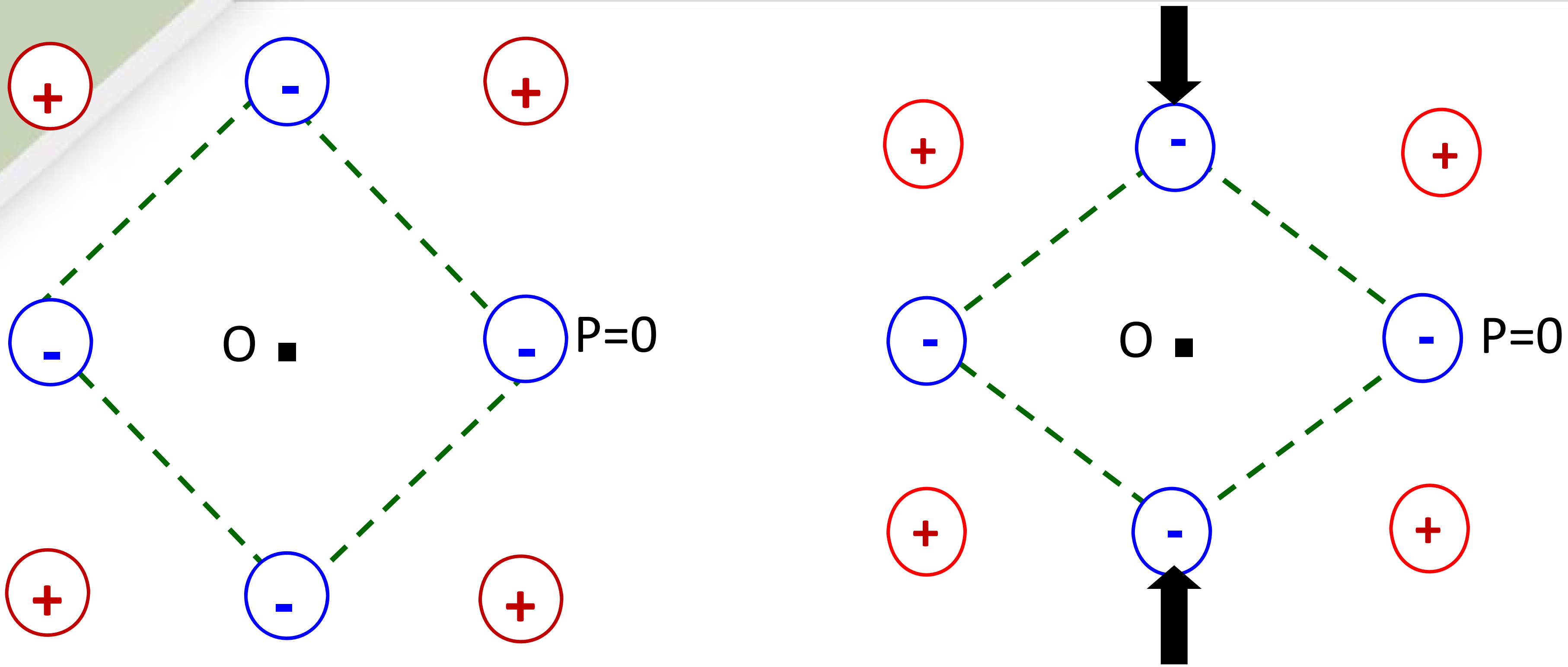
This provides a convenient transducer effect between mechanical and electrical oscillations



Piezoelectricity

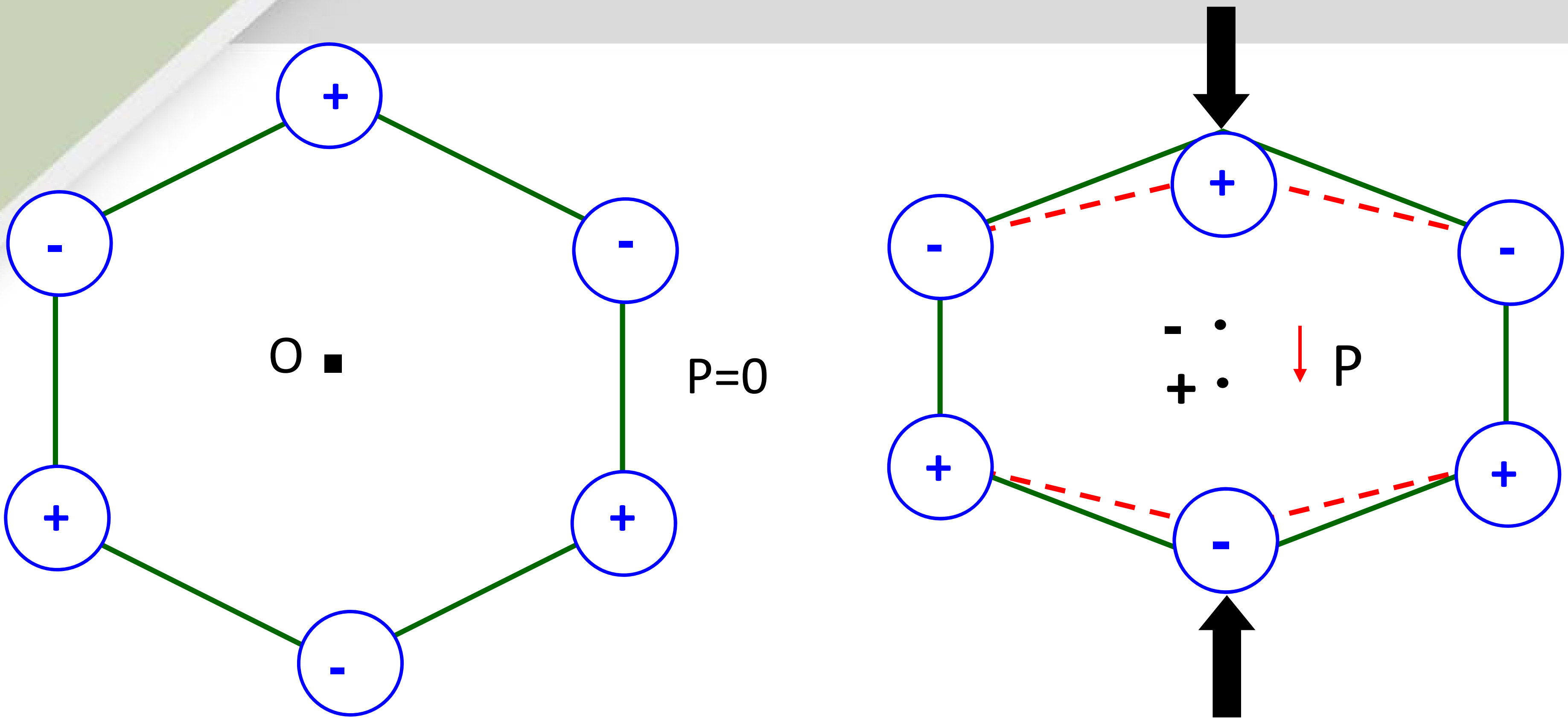
- Many crystalline materials exhibit piezoelectric behaviour
- Few materials exhibit the phenomenon strongly enough to be used in applications that take advantage of their properties
- Piezoelectricity is limited to crystals with low symmetry in single crystalline form, which requires that the crystal has no centre of symmetry

Piezoelectricity



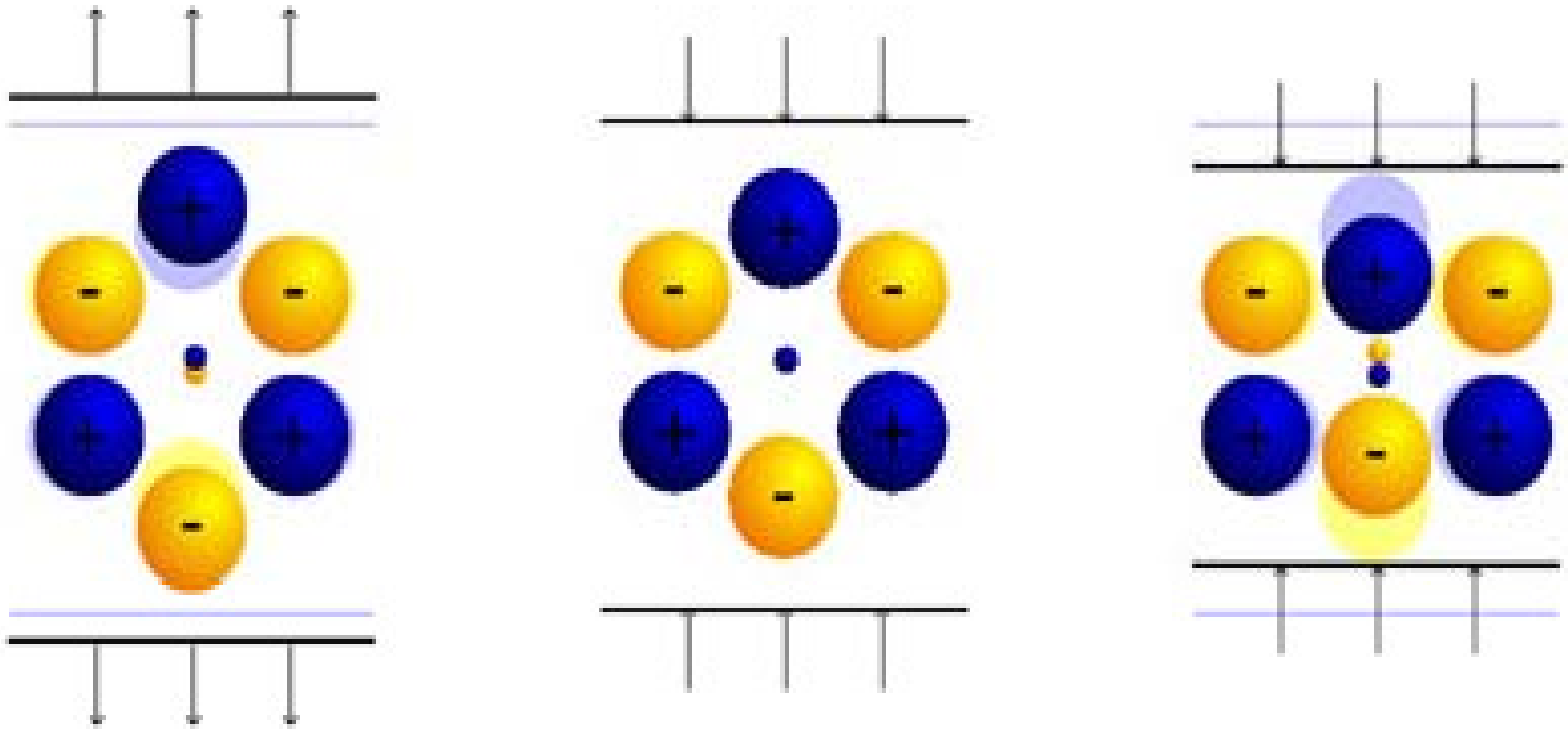
Crystal with centre symmetry

Piezoelectricity



Piezoelectric crystal without centre symmetry

Piezoelectricity



Piezoelectricity

Piezoelectricity has several major utilizations

The quartz oscillators, where suitable pieces of single crystal of quartz are given a very precisely and purely mechanically defined resonance frequency

When the piece of quartz is polarized by an electrical field of the same frequency, it will vibrate strongly, or else, it will not respond. This can be used to control frequencies at a very high level of precision

Piezoelectricity

Another application is the precisely-controlled movements

This is used normally with very small movements in the order of fractions of nm to µm

Piezoelectricity

The mechanical vibrations in quartz cause negligible losses and they have a high quality factor

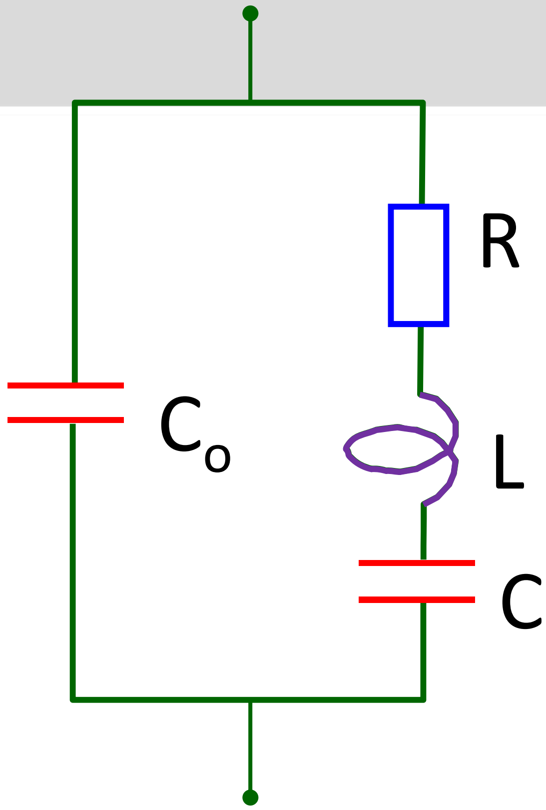
The mechanical vibrations have a nature that is in analogue to a resonant- series RLC circuit

The mechanical resonant frequency f_r is calculated as

$$\boxed{f_r = \frac{1}{2\pi\sqrt{LC}}}$$

Piezoelectricity

The parallel electrodes at opposite faces of the crystal form another capacitance that has to be modelled in parallel with the RLC circuit



There is another resonant frequency f_a due to L resonating with C and C_o in series:

$$f_a = \frac{1}{2\pi\sqrt{LC_{eq}}}$$

Where the equivalent capacitance $\mathbf{C_{eq}}$ is given by:

$$\frac{1}{C_{eq}} = \frac{1}{C} + \frac{1}{C_o}$$

Ferro Electricity

The name "Ferro Electricity" is not related to the Iron "Ferro", rather, it is correlated to the Ferro magnetism (in analogy with the ferromagnetic materials that already possess residual magnetization)

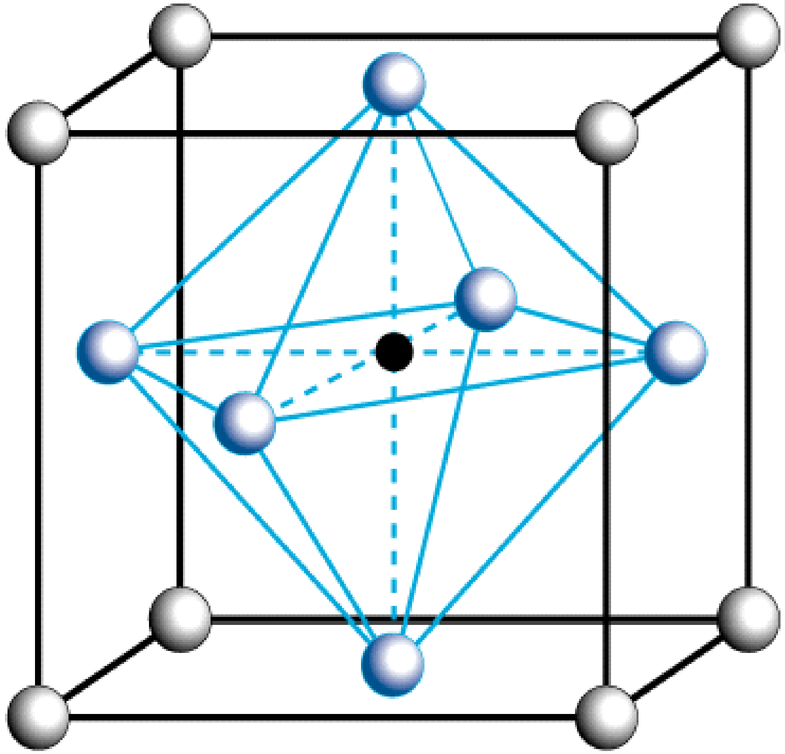
The electrical dipoles in some special materials are not randomly distributed but they interact with each other in such a way that they align themselves even without an external field

This situation results in spontaneous polarization and the material has a large value of dielectric constant

Ferro Electricity

An example of such materials that is used for many applications is the Barium titanate (**$BaTiO_3$**)

It has three different atoms with eight doubly charged **Ba^{2+}** atoms positioned on the corners of a cube, six **O^{2-}** ions on the face centres, and one **Ti^{4+}** ion in the centre of the cube



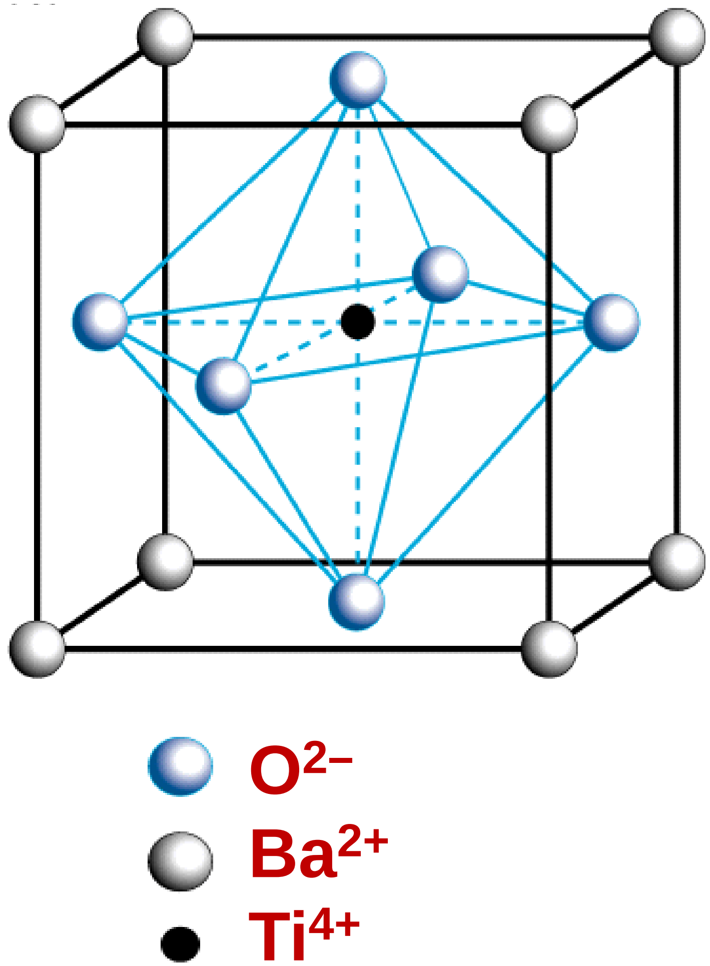
O^{2-}
Ba^{2+}
Ti^{4+}

Ferro Electricity

Each one of the eight **Ba^{2+}** ions belongs to eight cells and only one equivalent **Ba^{2+}** ion belongs to this elementary cell

Similarly, each one of the six **O^{2-}** ions belongs to two cells and each cell contains three **O^{2-}** ions

On the other hand, the **Ti^{4+}** ion belongs in total to the cell. It is clear thus that the structure is **$BaTiO_3$**



Ferro Electricity

Above a certain temperature (130 ^{o}C) the structure has a cubic unit cell

The centre of mass is of the negative charge **O^{2-}** and the positive charges **Ba^{2+}** and **Ti^{4+}** coincide at **Ti^{4+}** ion

There exists no net polarization

If the temperature is reduced lower than 130 ^{o}C, the lattice forms a slightly-distorted cubic

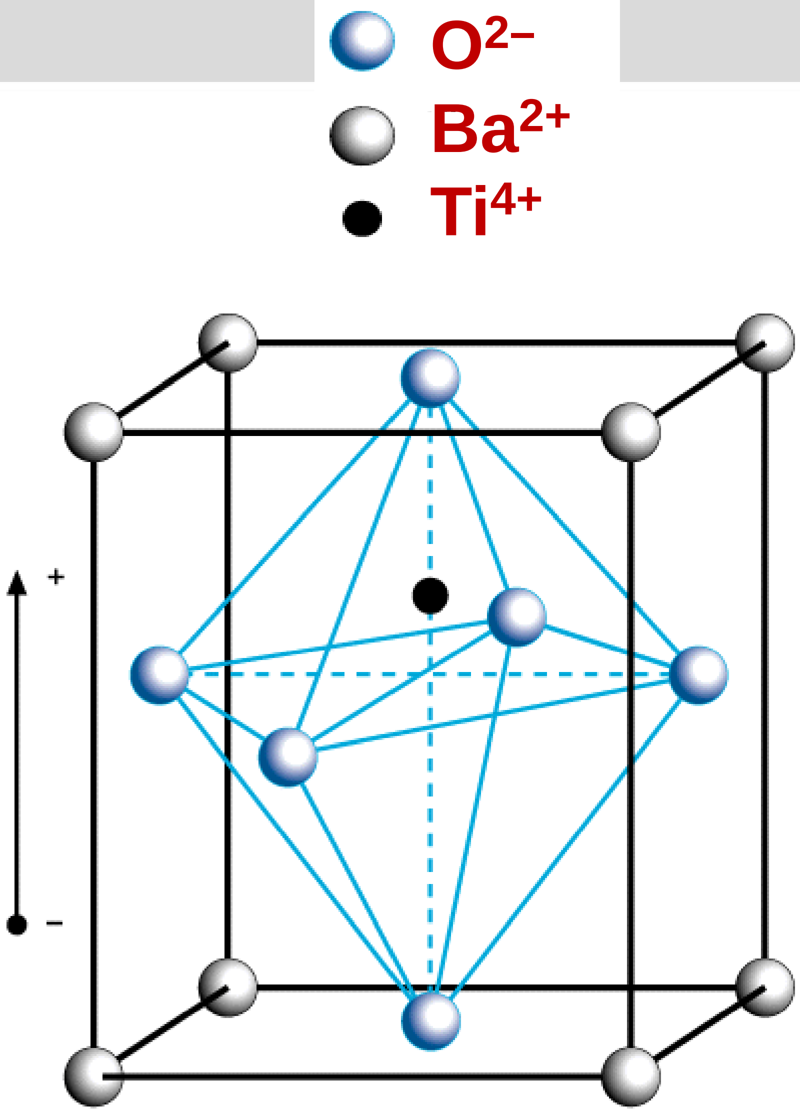
The **Ti** - ion does not sit exactly in the centre of the cube

This shift in the **Ti** – ion results in a dipole moment in each elementary cell

Ferro Electricity

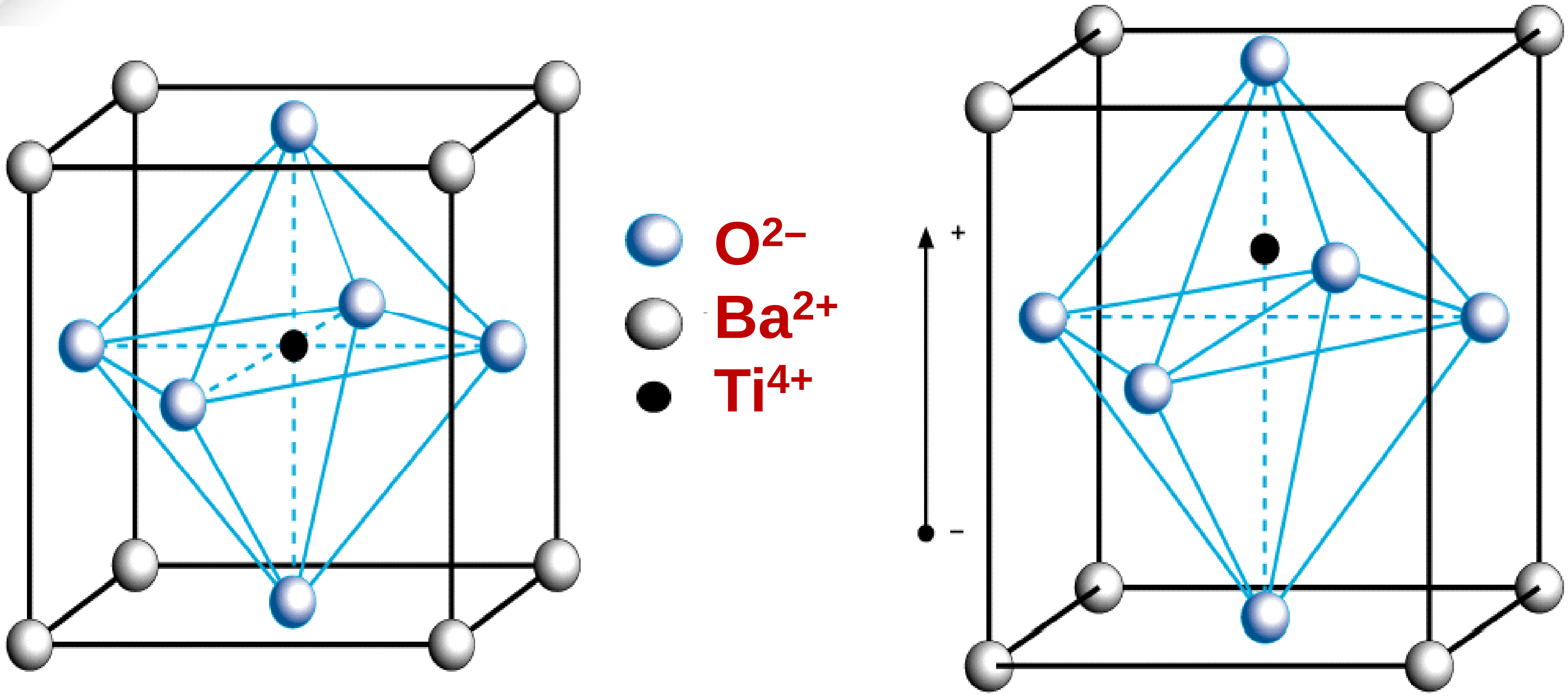
The dipole moments of the neighbouring cells tend to line up

This characteristic can be useful when used with capacitors that use ferro-electric materials with high dielectric constant values



Ferro Electricity

The critical temperature, above which Ferro electricity is lost, 130 °C in this case, is called **Curie temperature**



Magnetic Materials

The description of the interaction of materials with magnetic fields is equivalent to that with the electric field

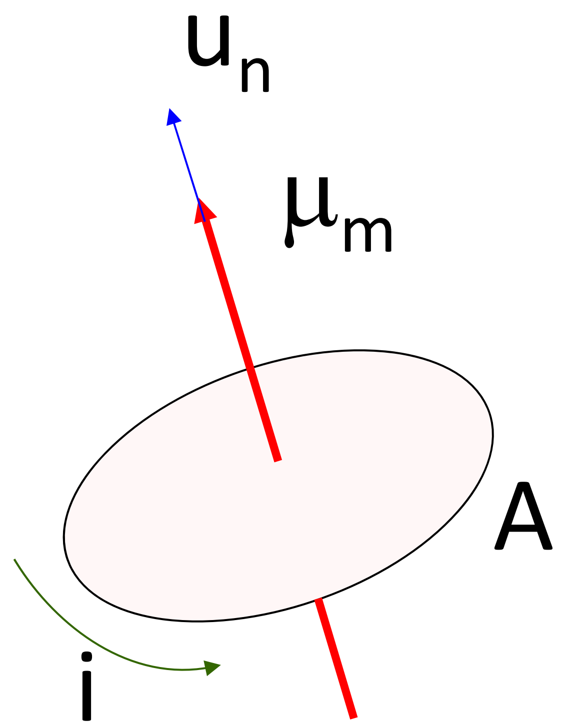
The magnetic field is characterized by the magnetic field intensity with units of Ampere-turn/meter (A/m), and the magnetic flux density with units of Weber/m^2 (Wb/m^2) or Tesla

Obviously, B and H are vectors

Magnetic Dipole Moment

The torque acting on a current-carrying coil can be related to the characteristics of the coil by the magnetic moment or magnetic dipole moment

For the current loop, the circulating current is **I** and the area enclosed by the current is **A**



Magnetic Dipole Moment

The magnetic dipole moment μ_m is defined as:

$$\mu_m = i\ A\ u_n$$

Where, **u_n** is a unit vector perpendicular to the area **A**
The magnetic moment is a vector with direction perpendicular to the current loop in the right-hand-rule direction
With **N** loops, the equation is multiplied by (**N**) as:

$$\mu_m = N\, i\ A\ u_n$$

Magnetic Dipole Moment

When the magnetic dipole moment is inserted inside a magnetic field, it will be subjected to a magnetic force (including both sides of the coil) and it will rotate to have its axis in the direction of the magnetic field

The torque exerted by the magnetic force is given by:

$$T_m = \mu_m \; B \sin(\theta) = i \; A \, B \sin(\theta)$$